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Title: Phenomena Associated with Magma Expansion into a Drift

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Phenomena Associated with Magma Expansion into a Drift

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Introduction: One of the significant threats to the proposed Yucca Mountain nuclear waste repository has been identified as the possibility of intersection of the underground structure by a basaltic intrusion [1]. Based on the geology of the region, it is assumed that such an intrusion would consist of an alkali basalt similar to the nearby Lathrop Wells cone, which has been dated at about 78 ka [2]. The threat of radioactive release may be either from eruption through the surface above the repository of basalt that had been contaminated or from migration through ground water of radionucleides released as a result of damage to waste packages that interact with the magma [3]. As part of our study of these threats, we are analyzing the phenomena associated with magma expansion into drifts in tuff. The early phenomena of the encounter of volatile-rich basaltic magma with a drift are discussed here.

Work Description: CFDLIB is a code library for computational fluid dynamics developed by Los Alamos National Laboratory for simulation of multi-material, multi-phase fluid-structure interaction problems in two or three dimensions [4]. We have modified this library to address some specific issues related to volcanic activity [5]. Specifically, we have included the equation of state of mixed H2O-CO2 gas after the manner of Papale [6], and a temperature- and volatile-dependent viscosity with Shaw's method [7]. Simulations have been run of the expansion of magma with 0.5-4.0% by weight of water into empty circular drifts and into drifts with blockages representing waste canisters.

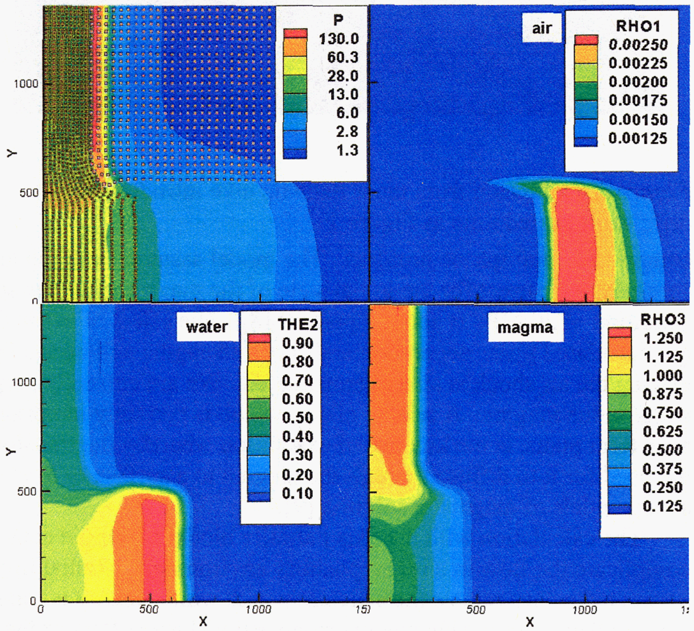

Figure 1. Early expansion of wall of magma into drift.

Results: Typical results for the early expansion of magma into an empty drift indicate that the process is quite complicated. Using a four-material model with air in the drift and in the pore spaces of rhyolite tuff and magma consisting of basalt liquid and water vapor, we start with a wall of magma at one end of a 2-dimensional cylindrical drift. The magma expands into the drift with water vapor (2 percent by weight) separating from the basalt liquid. With this abrupt beginning, the expanding products drive a shock down the drift.

This is illustrated in Figure 1, which shows the pressure (bars, upper left), air density (gm/cm^3, upper right), volume fraction of water vapor (lower left) and bulk density of silicate liquid (gm/cm^3, lower right) 20 ms after the vertical wall of wet magma is exposed to the air in the drift. The location of the silicate liquid is shown by the green-on-red tracer particles at the left edge of the pressure plot, and the surrounding tuff is indicated by the blue-on-orange tracers. By this time, the flow is separated in to distinct phases with a shock wave in air reaching to about 13 m. This shock is driven by the leading edge of the expanding water at about 6 m, while the silicate liquid has not yet expanded beyond 4.5 m. At later times, this phase separation increases. Drag coefficients between pairs of the four phases are an input variable in these calculations, and separation between the magma components will vary as the water/silicate drag is changed.

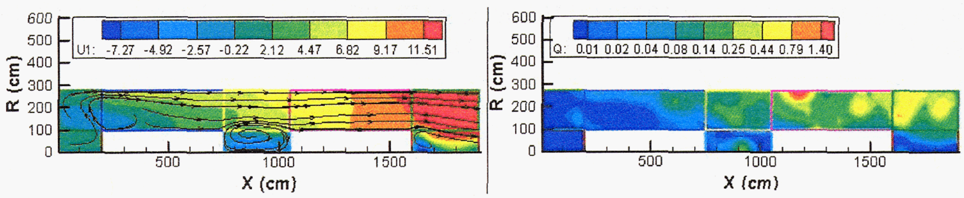

Figure 2. (Left) velocity along drift direction (with some representative streamlines) and (right) dynamic pressure of flow with axial obstructions.

With rigid cans along the axis of the drift, the flow seen in Figure 2 is even more complicated. These plots show only the drift. Eddies form between the cans, and dynamic pressures put substantial loads on the cans and on the walls of the drift. The early phase separation illustrated in Figure 1 was also observed in this calculation, although later remixing does occur. At the time shown in Figure 2, the bulk density above the cans in about 0.1 Mg/m^3 with almost all the mass being basalt liquid, but water vapor is the major constituent on a volume basis.

In a third calculation, the dike was modelled coming in from the edge, moving toward the drift at a typical dike propagation speed of 1 m/s. This is illustrated in Figure 3. (These simulations are done with cylindrical symmetry about the axis of the drift and with out gravity, so there is no real "up" or "down" in the figures.) The calculation begins with an opening only about 0.17 m wide at the tip of the dike, although this slowly widens as the magma intrudes the drift. The small aperture restricts the flow so that, at the same scaled time as shown in Figure 1, pressures in the dike have not reached 200 kPa (upper left), and no shock wave has formed. However, the tapered front to the dike and its movement toward the drift have already caused considerable deformation of the tuff adjacent to the dike, as can be seen from the blue-on-orange tracers. The magma is still virtually completely restricted from the drift at this early time (lower right), and the water vapor has only just begun to emerge (lower left).

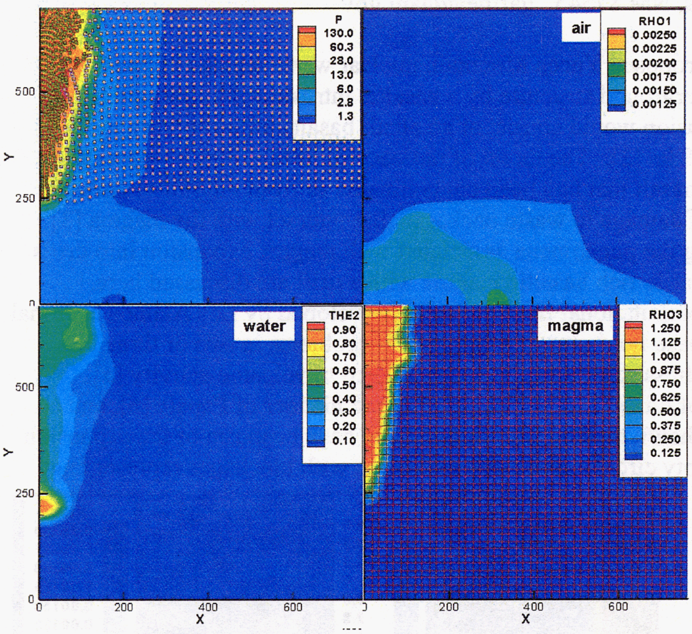

Figure 3. Expansion from more realistic dike intruding into drift; same scaled time as Figure 1.

Conclusions and Discussion: Our results agree with numerous field observations that the interaction between magma and air is a complicated multiphase problem. The model assumed that the total water content of the magma was vapor which is certainly not correct for the initial state of the magma since the solubility of water in basalt magma at our initial condition of 20 MPa is about 1 percent [8]. The effect of not including solubility of water in the basalt will be that our calculated phase separation and shock strengths will be too large. Likewise the length of the water vapor slug driving the air shock is also overestimated. We are currently preparing a model which will include the solubility of water in the magma. A related effect, which is certainly important but which is not included in our model nor in our near-term plans, is the kinetics of exsolution whereby the transformation of water to the vapor phase is retarded by the need for it to diffuse through the magma to a surface or to nucleate a new bubble. This has been addressed in some models of magma exsolution [9].

The calculation with the axis partially blocked by rigid cans illustrates some of the phenomena that are likely to complicate the flow in a real repository environment. Radial flow and mixing associated with formation of eddies between the cans reduce the efficiency with which energy is transferred down the drift to sustain shock waves. This is more than a simple change in cross-sectional area effect of the sort addressed in calculations by Woods et al. [10].

Based on a comparison of the results illustrated in Figures 1 and 3, it appears that use of more realistic models for the initial interaction between an intruding dike and a drift diminishes, if not eliminates, the threat of shock wave formation during the early parts of the dike-drift interaction. This also is consistent with observations of the early parts of the eruption of Pericutin [11].

References: [1] threat is basalt cone. [2] like Lathrop Wells. [3] threat may be eruption or groundwater. [4] old CFDLIB reference. [5] CFDLIB version 02.1 Requirements Document,. CFDLIB version 02.1 Design Document. [6] Papale, 1999. [7] Shaw, 1975? [8] Valentine AMR. [9] magma exsolution kinetics [10] Woods et al. Geophys. Res. Lett. 29 (13), 10.1029/2002GL014665, 2002.